The Effects of Light-Induced Degradation on the Electronic Properties of Hydrogenated Nanocrystalline Silicon

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OUTLINE

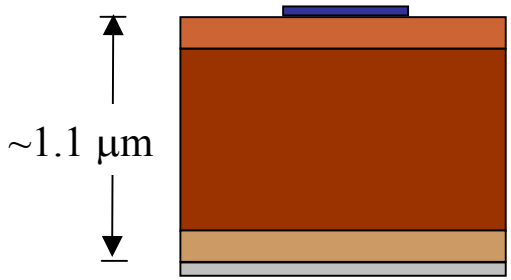
- **Types of Nanocrystalline Silicon Samples Studied**
- **Drive Level Capacitance Profiling**
  Effects of hydrogen profiling and Light Soaking
- **Transient Photocapacitance and Photocurrent Spectroscopy**
  Temperature variation shows degree of minority carrier collection
- **Light-induced Degradation**
  Reduces the minority carrier collection
- **Conclusions**

Types of Nanocrystalline Si Devices Studied

PIN

SS/n+/i/p$^+$/TCO

Deposited at : United Solar Ovonic Corp.



Advantages:

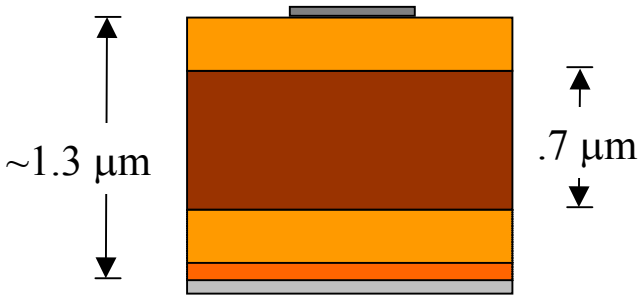
- Purely nc-Si:H

Disadvantages:

- Has thin heavily doped p and n layers

SANDWICH

SS/n+/a-Si:H/nc-Si:H/a-Si:H



Advantages:

- Purely intrinsic
- Blocks diffusion of O_2

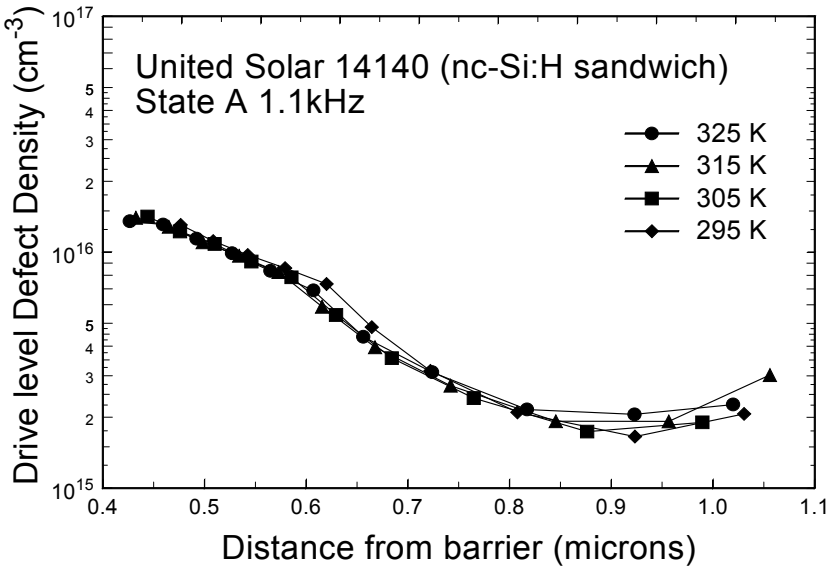
Disadvantages:

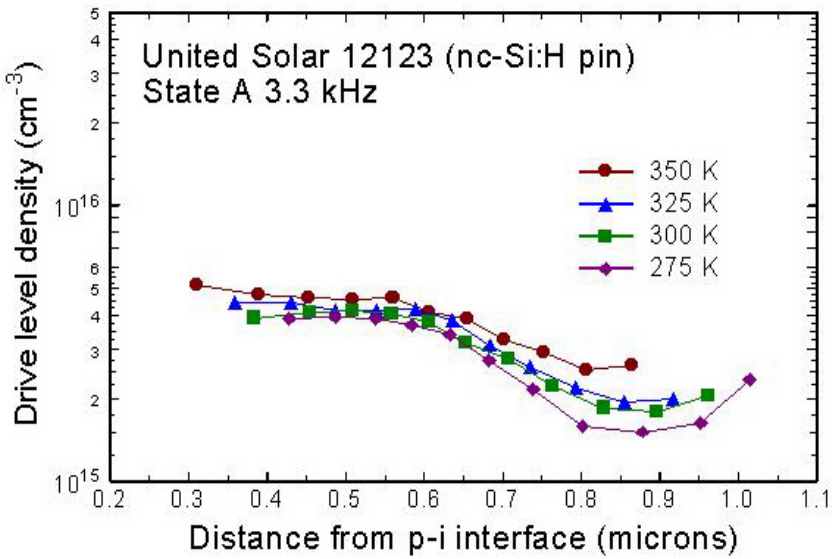
- Contains a-Si:H layers

We made measurements on both device types to isolate the spectral features due to the intrinsic nc-Si:H layer itself

Results from Drive-Level Capacitance Profiling

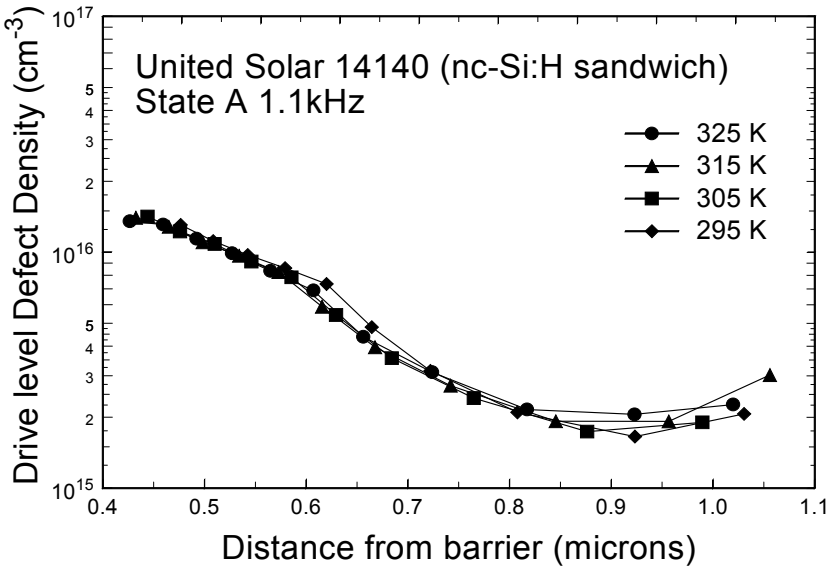
DLCP for nc-Si:H Films Deposit under Constant H-Dilution

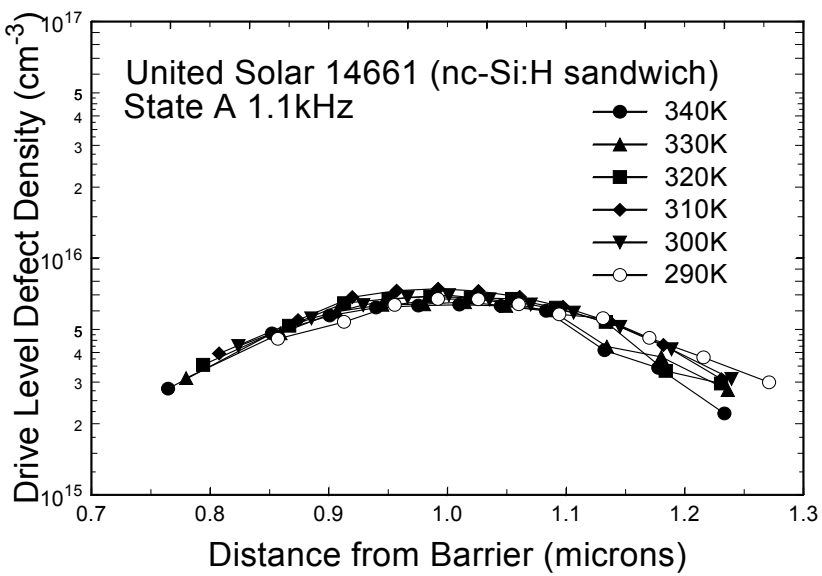




- Response suggest responding states are ***shallow donor-like states***
  - These states appear to lie within about 0.55eV of the conduction band edge
- The p-i-n device shows a similar spatial distribution of states that increase in the direction of the growing film
  - Grains become larger as the films become thicker hence more defective
- These films were deposited without hydrogen profiling

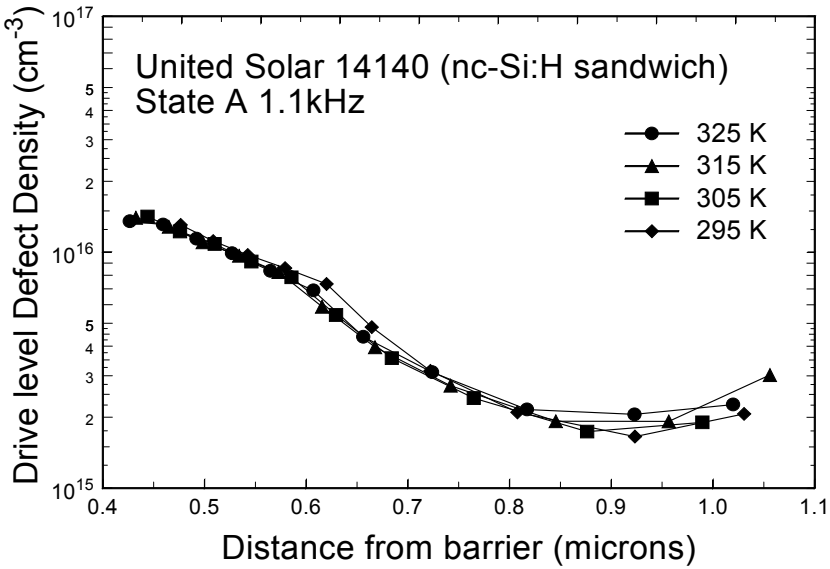
DLCP Results for Constant Hydrogen vs. Profiled Hydrogen

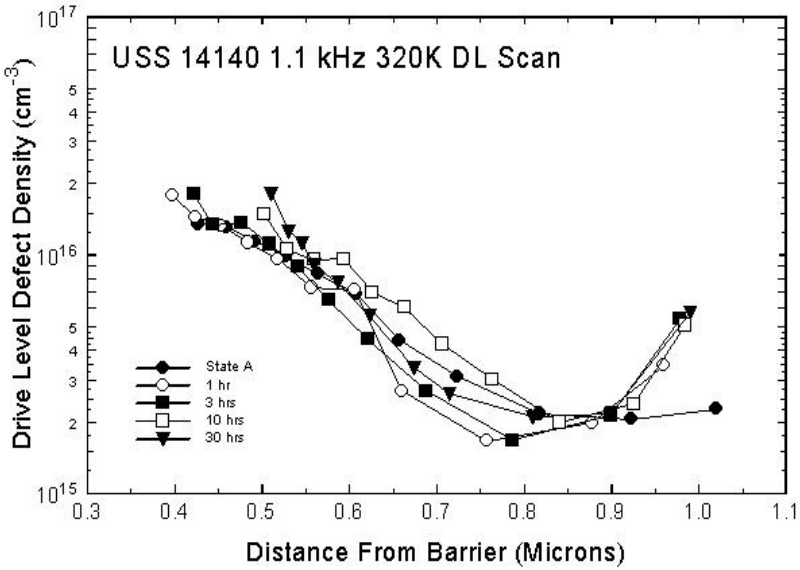




- For one sandwich sample the hydrogen dilution was varied to control the evolution of crystalline volume fraction and crystallite size
- The profiled sample exhibits a DLCP profile that reaches a maximum within the middle of the film but then decreases again
- Hydrogen profiling is also found to lead to an increase of nc-Si:H solar cell efficiency

Effects of Light Soaking on Defects Observed using DLCP



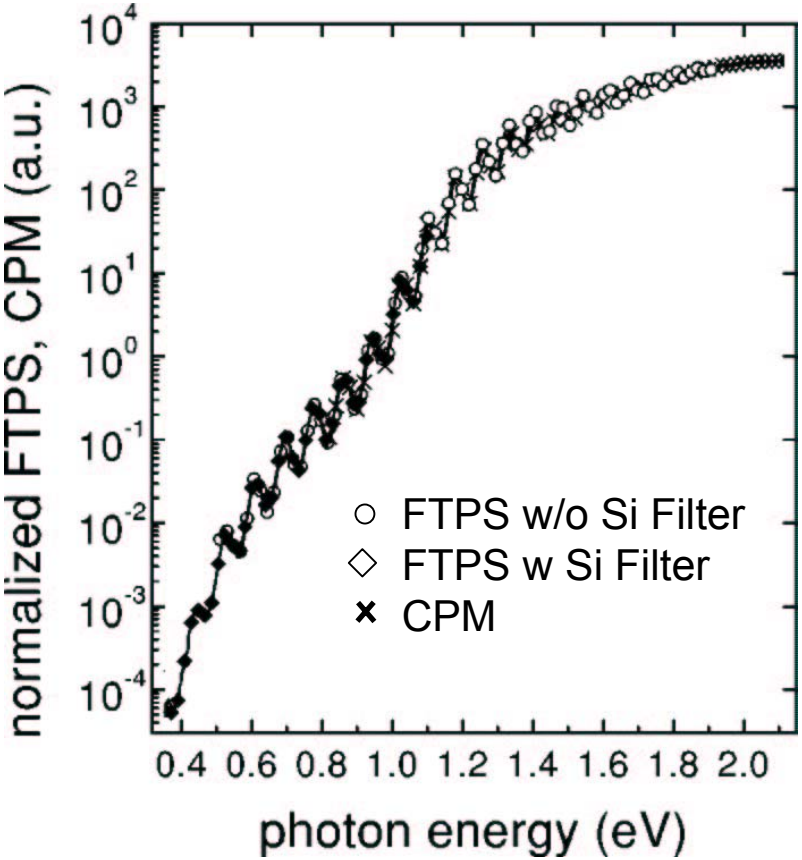


- Apart from slight horizontal shifts, **light soaking does not** appear to affect these drive-level profiles.

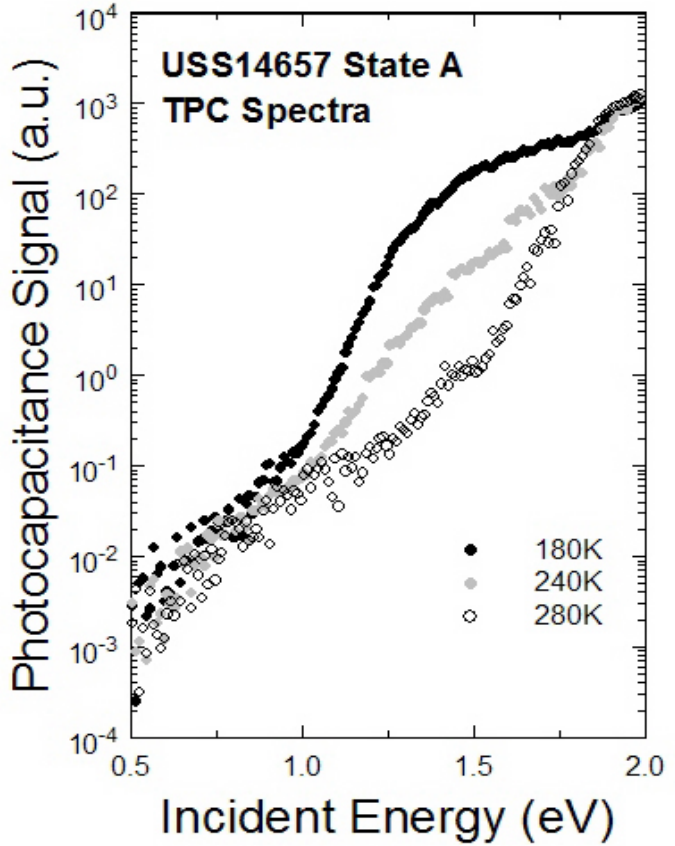
Transient Photocapacitance and Transient Photocurrent Spectroscopy

Comparing CPM and Photocapacitance Spectrum for nc-Si:H

Fourier-Transform Photo Current Spectroscopy(FTIR) and CPM Spectra



Very temperature dependent!



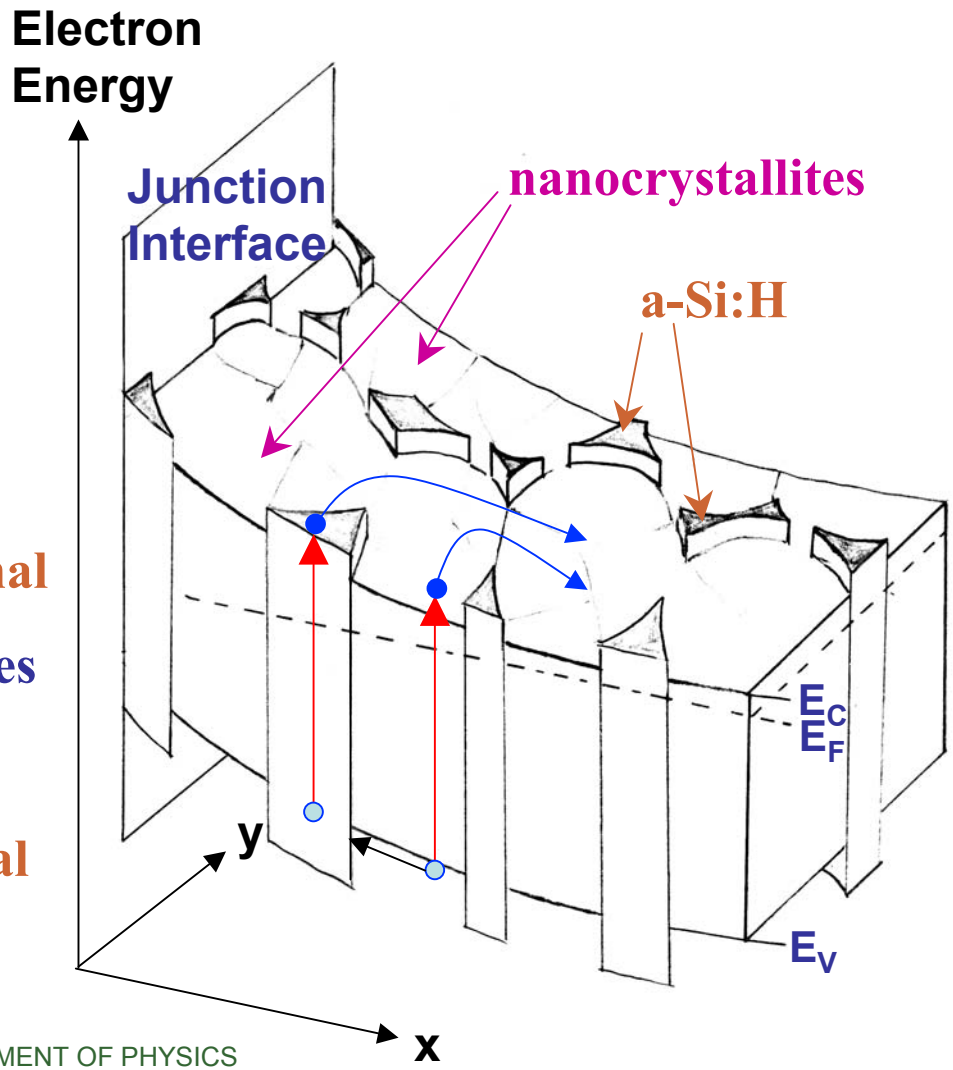
At higher temperatures spectra resemble those of a-Si:H

Hole Collection Inhibited in a-Si:H Component

At photon energies greater than 1.1eV, free electrons and holes excited in nano-crystallites.

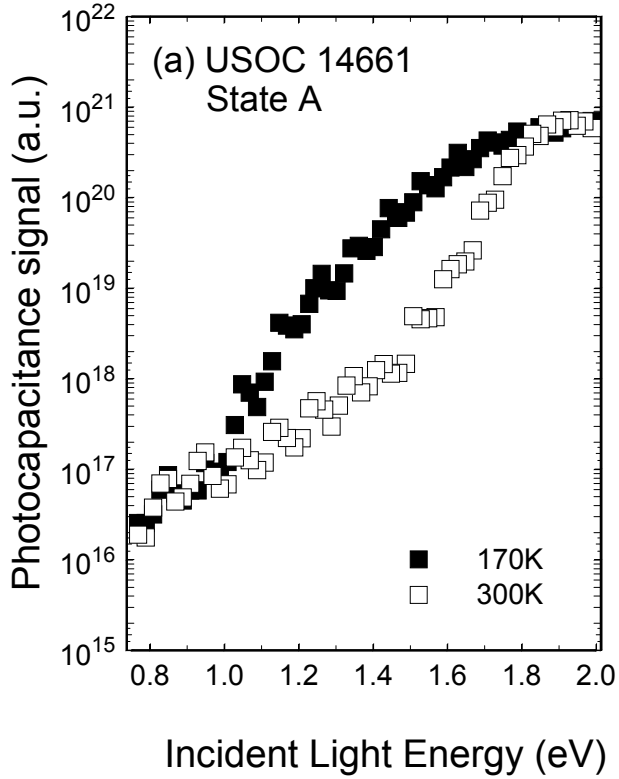
At moderately high temper-atures both carriers escape
⇒ little change in charge
⇒ small photocapacitance signal

In a-Si:H component many holes remain trapped
⇒ mostly electrons escape
⇒ large photocapacitance signal

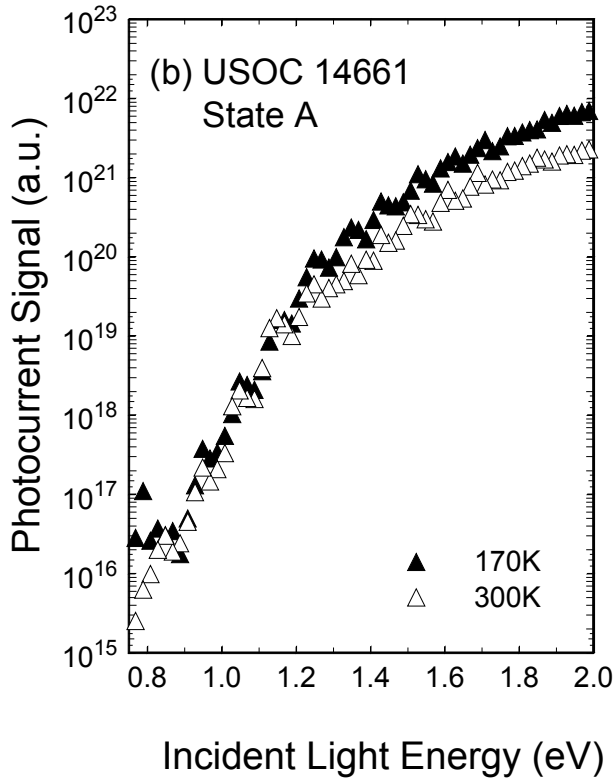


Minority Carrier Collection Increases with T

Transient Photocapacitance



Transient Junction Photocurrent

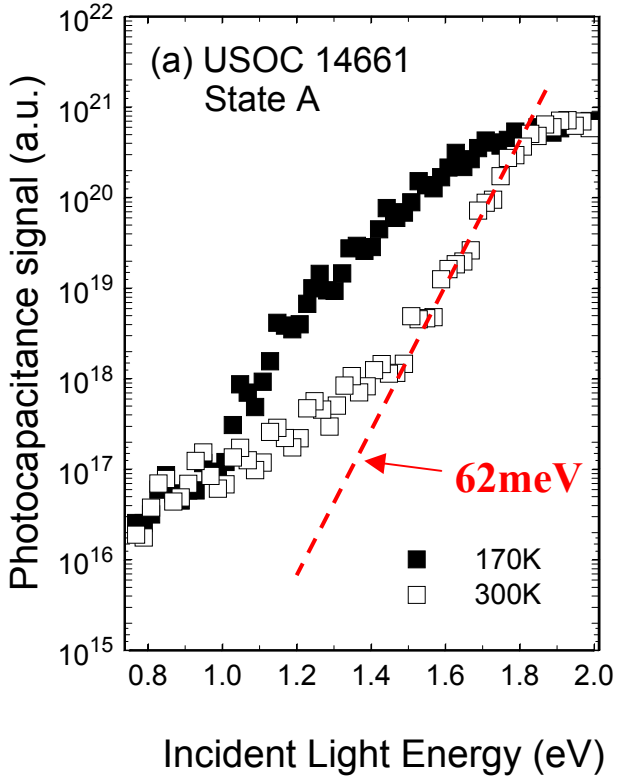


Increased minority carrer collection suppresses signal in nc-Si:H component

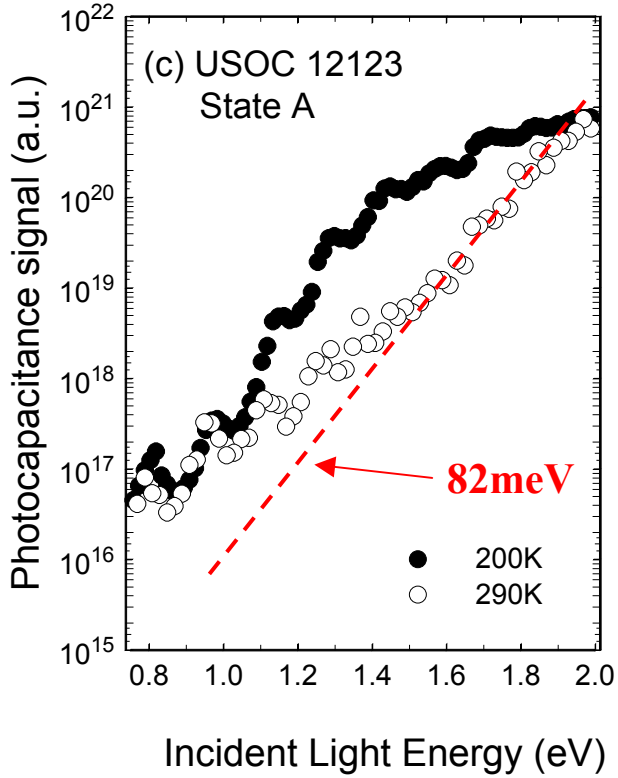
Photocurrent signal dominated by nc-Si:H component at all T

a-Si:H Component Seen in all Samples

Sandwich Sample (H-profiled)



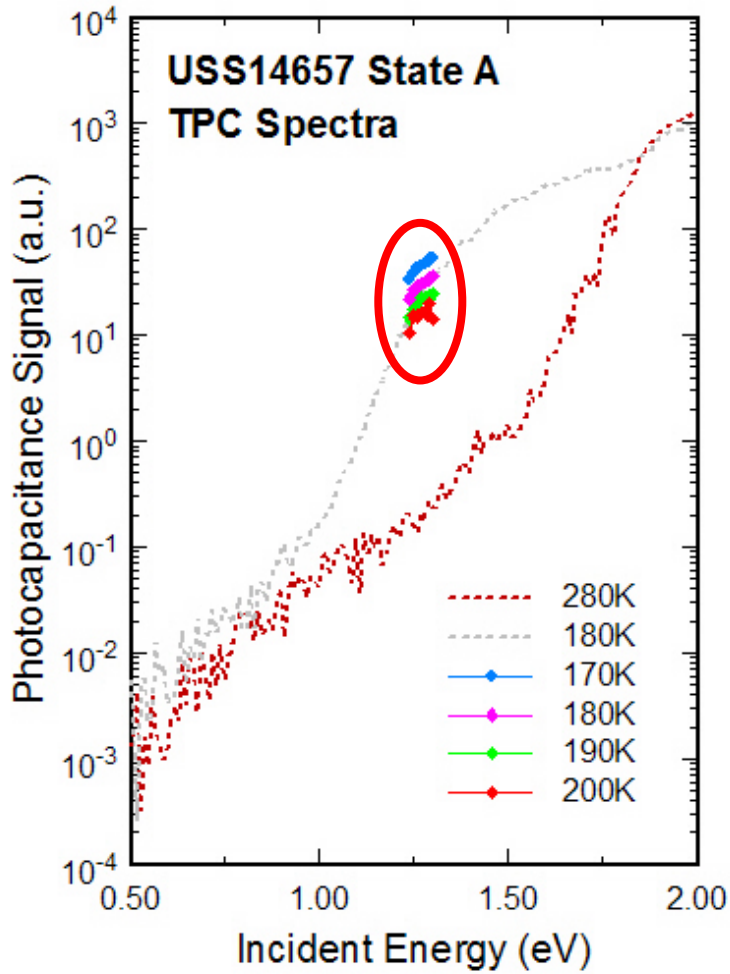
pin Sample



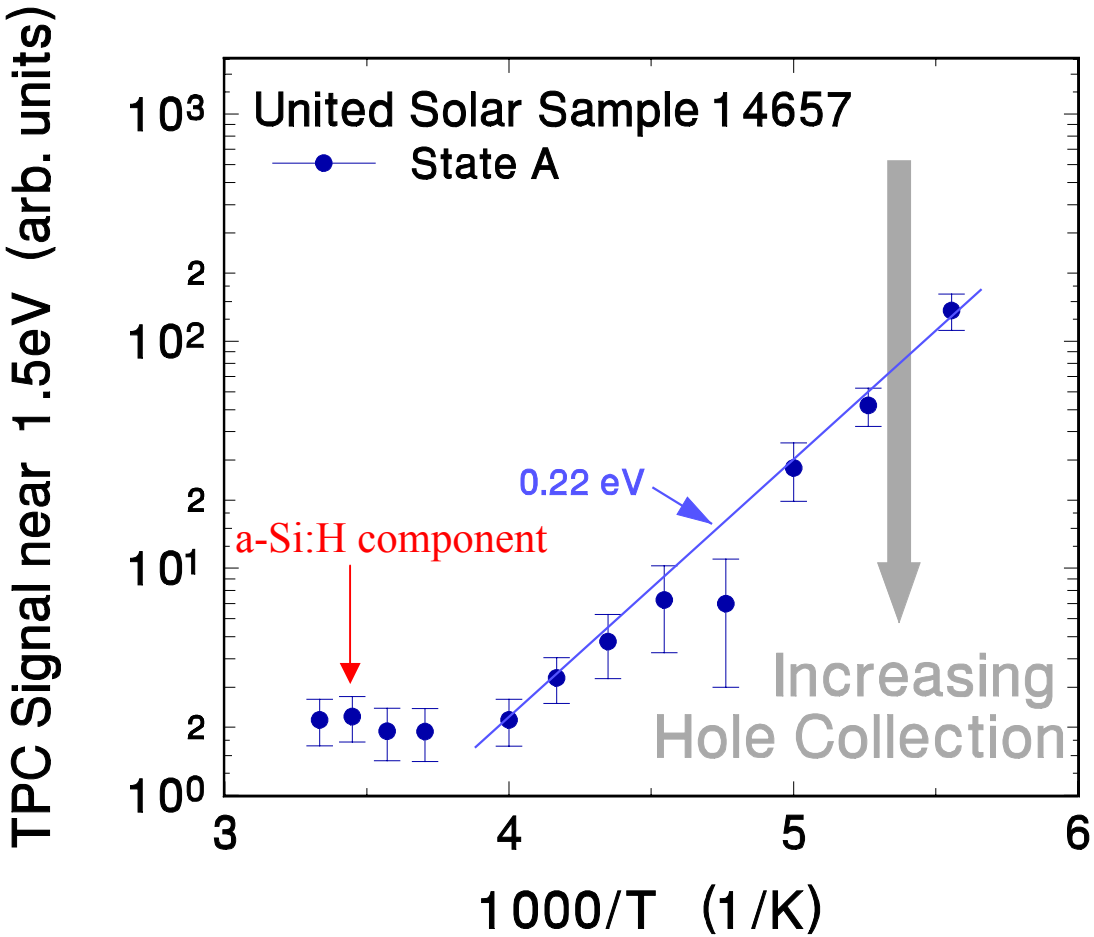
Indicates a-Si:H is present in nanocrystalline silicon as an integral component

Minority Carrier Collection is Activated

- When the nc-Si:H component of the spectrum is small, minority hole collection is large
- We examined the detailed temperature dependence in the region shown

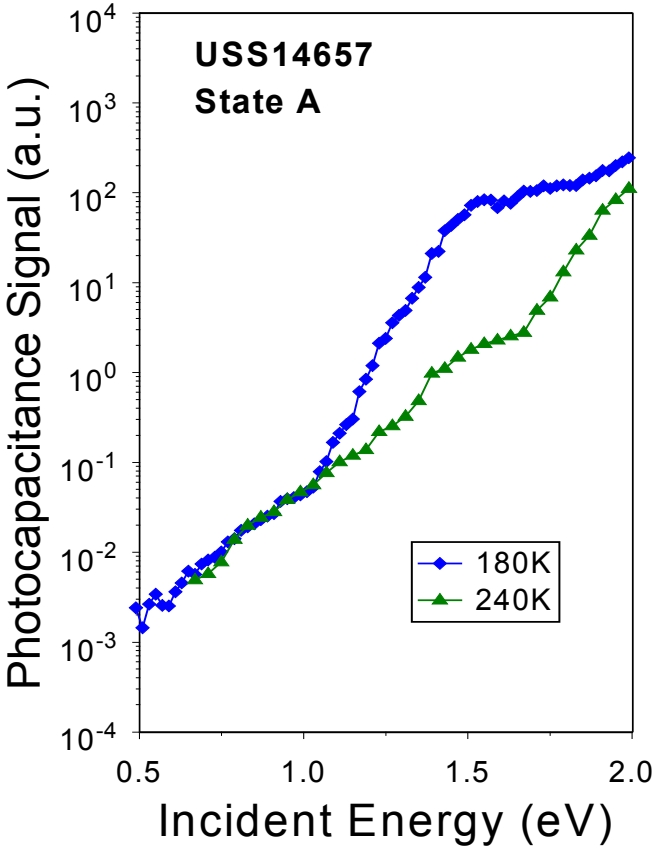


Hole Collection in Crystalline Component is Thermally Activated



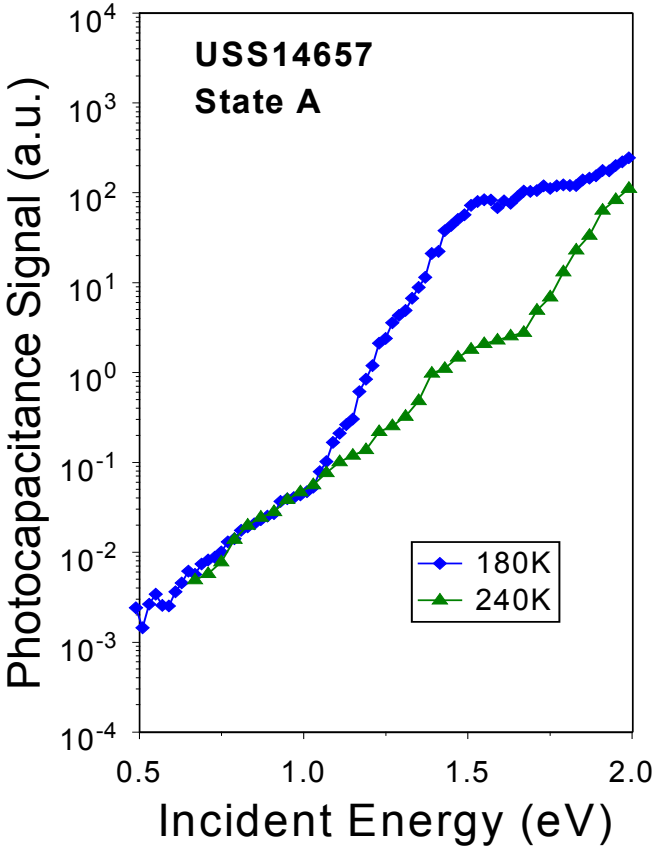
Light-Induced Degradation in nc-Si:H is Associated with a Reduction in Minority Carrier Collection

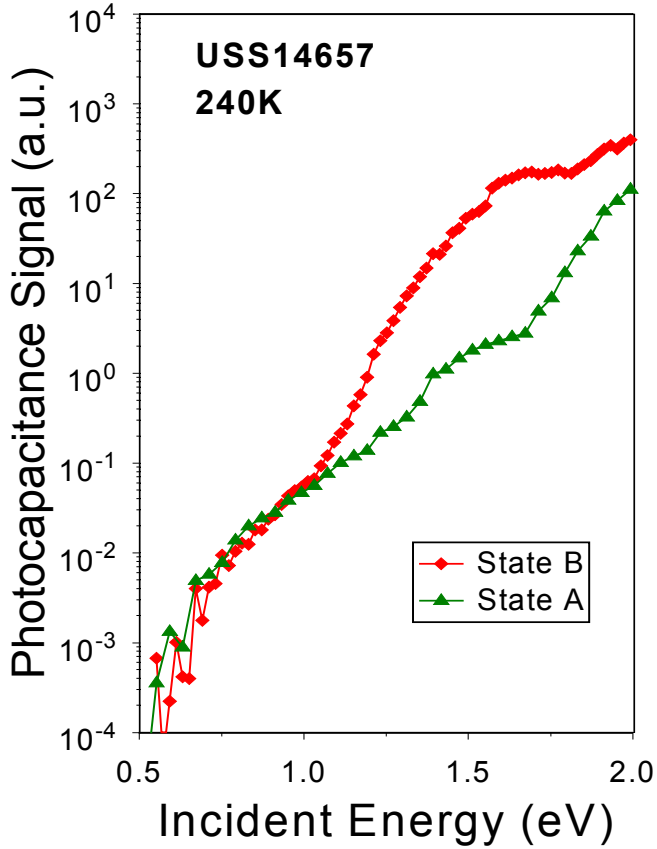
Hole Collection is Reduced at Lower Temperatures



By reducing the temperature from 240K to 180K, hole collection in the nanocrystalline component of this sample is reduced by at least a factor of 50.

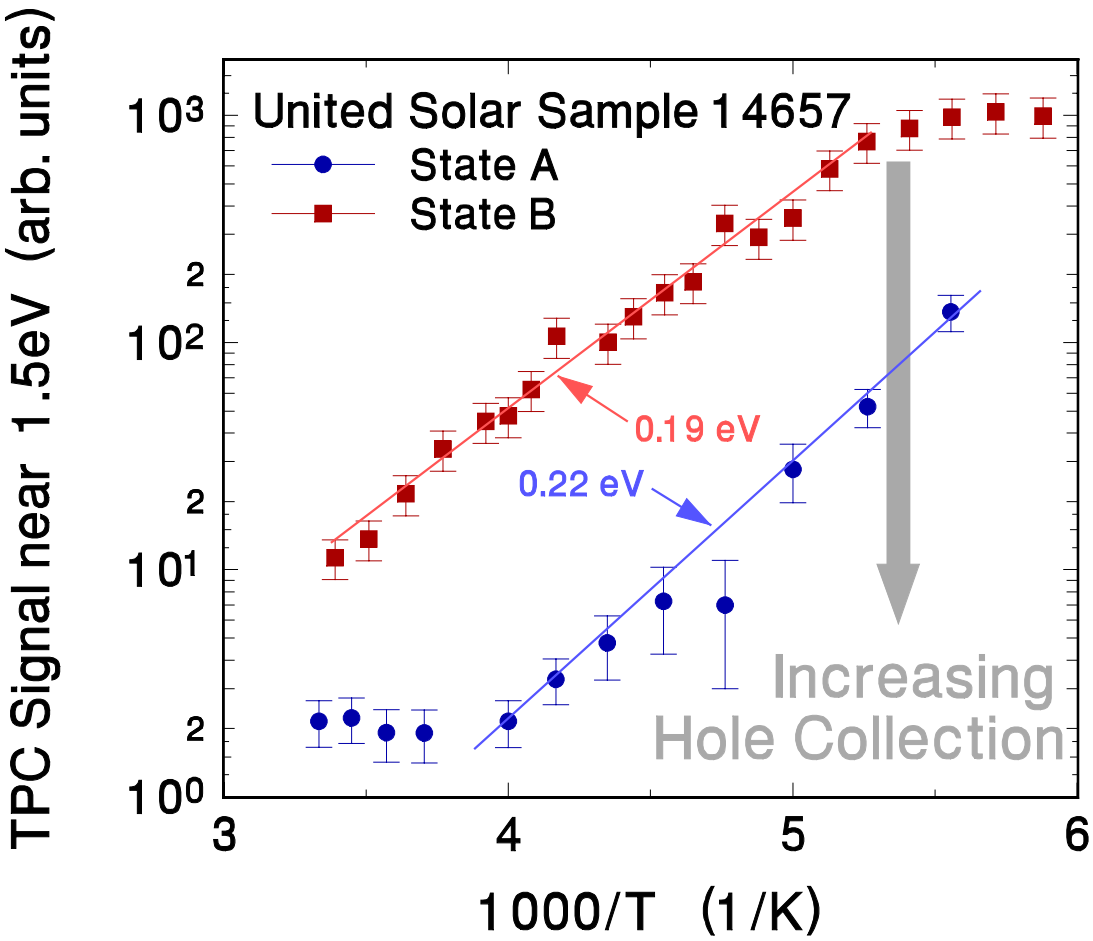
A Similar Reduction Occurs after Light-Soaking!





Light-soaked State B at 240K displays a similar reduction in hole collection

Hole Collection Also Thermally Activated in State B

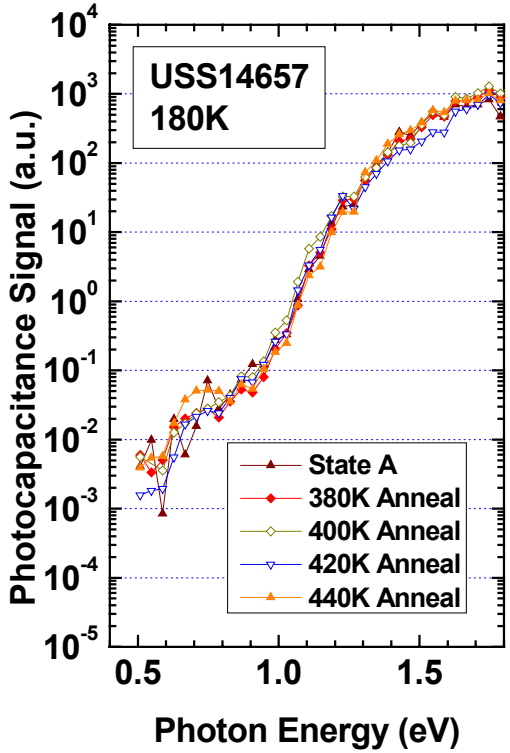


- Similar activation energies are exhibited in both the degraded and annealed states.
- Hole collection reduced after light soaking by roughly a factor of 20 at nearly all temperatures
- Suggests same hole traps are responsible in both cases, but that there are ***more of them in State B***

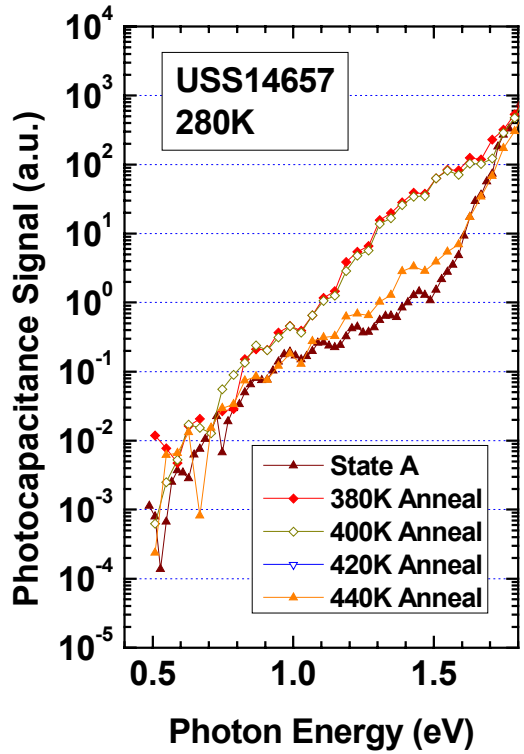
Is an Increase in Deep Defects Responsible?

NO – Negligible changes in 180K sub-bandgap spectra for series of metastable states

At higher temperatures one sees the differences related to hole collection
Deep defect region still unchanged



Series of anneals at increasing temperatures from State B back to State A



Conclusions

- States observed using DLCP appear to be shallow and donor-like and their profile does not change significantly with light soaking
  - –Their distribution and density can be modified by hydrogen profiling
- High quality optical spectra for nc-Si:H were obtained using transient photocapacitance spectroscopy
  - – Can separate the nc-Si:H component from the a-Si:H component by changing the measurement temperature
  - – Can determine an activation energy for minority carrier collection
- Light soaking leads to a degradation in minority carrier collection
  - – Our results are correlate with the observed degradation of electrical properties in nc-Si:H solar cells found after light exposure
  - – This degradation does not appear to involve an increase in the dangling bond density that can be observed in our sub-bandgap spectra